International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 10, Issue 2, Apr 2020, 357–368
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ANALYSIS OF THE THERMAL BEHAVIOR IN THE GOLDWIND S50/750 WIND TURBINES INSTALLED IN THE WIND FARM GIBARA II USING CAD-CAE TOOLS

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ABSTRACT

This study indicates the thermal behavior inside the gondola for models S50–750 of Goldwind wind turbines installed in the Wind Farm Gibara II. It allows the early diagnosis of incipient failures that occur in the studied devices because of the high temperatures generated in its components under the operating conditions of Cuba. It works in the obtention of the values of the thermal state using forecast statistics and computer-aided design and engineering software (CAD-CAE), such as SolidWorks and its Flow Simulation add-on. This research supports its theories and postulates in the study of six assembled devices of Chinese origin, which have been in operation for nine years. For that purpose, we used a database that collects the temperature measurements in different working conditions and points inside the gondola.

KEYWORDS: Thermal Behavior, Goldwind Wind Turbines, Wind Farm, Temperatures & CAD/CAE Tools

Received: Dec 01, 2019; **Accepted:** Dec 21, 2019; **Published:** Mar 09, 2020; **Paper Id.:** IJMPERDAPR202032

Original Article

INTRODUCTION

For many years, men have been using renewable energy sources, such as solar, wind and hydro. They were first used many centuries ago and continued to be used throughout history until the arrival of the "Industrial Revolution", during which they were abandoned due to the low price of oil (Aenor, 2006). In the first year of the 20th century, the applications of windmills for electric generation began to appear. Aerodynamic theories allowed to establish the basic operating principles of the new wind turbines, achieving optimized designs. Not before having gone through multiple models that include the horizontal and vertical axis. During the last years, due to the increase in the cost of fossil fuels, the predictions of hydrocarbon potential and the environmental problems derived from its exploitation, there is a revival of renewable energies.

It is estimated that the use of renewable energy sources will triple in the next 20 years globally. In addition, the European Union, which reaffirms its goal of 20% renewable final energy by 2020, and other regions in the world with specific renewable goals, renewable energies are a fundamental component nowadays, and a viable and competitive future alternative. This generalized use will be led by the electricity sector, where the competitiveness of renewable technologies has already reached maturity levels, higher than those of conventional technologies. It is expected that the supply of renewable electricity globally will increase by more than 60% between 2012 and 2030 (Goldwind Science & Technology, 2007).

Generation of wind energy is closely linked to the performance of operational work for the exploitation of systems and technical repair or exchange services, which can be divided into four groups (reviews and small,

medium and general repairs), essentially different according to their character and equal in its objective: to keep the device available (Limas *et al*., 2017).

Therefore, there have been multiple research lines and scenarios, where scientists concentrate their efforts. Analyzing: "Considerations of the lifetime and control of fatigue loads in wind turbines (Njiri *et al*., 2019). Sensitive studies to optimize maintenance of wind loads on the blades, vibrations in bearings, all applying data monitoring through SCADA systems (Oliveira *et al*., 2018; Zhang and Lang, 2018; Gonzalez *et al*., 2018; Cheng *et al*., 2018; Gonzalez *et al*., 2019; Limas *et al*., 2019). Due to the rapid development of computer sciences and mathematics, mathematical models have been developed and used to boost the efficiency in the generation, maintenance and design of wind turbines (Wu and Wang, 2018; Taher *et al*., 2018; Rinaldi *et al*., 2018; Niu *et al*., 2018; Liu *et al*., 2018; Hu, 2018). The results of many investigations converge on the existence of systems and aggregates with a high weight in the criticality of the functional states, which is why they have concentrated their researches on studying and detecting failure modes in gearboxes, generators and data acquisition systems (Artigao *et al*., 2018; Nejad *et al*., 2018).

Wind turbine installations in areas, where the climate reaches high temperatures and/or high humidity percentages have the inconvenience that these wind turbines must work in nominal conditions, not being able to work at maximum capacity. One of the main causes of this drawback lies in the limitations that mark the internal components of the wind turbines located in the gondola of the wind turbine compared to the temperature, as is the case of the gearbox and generator (Artigao *et al*., 2018).

The use of computers as a tool to help different human activities has become so important that today it is almost inconceivable to survive without them in such a competitive world. It can be said that its application has covered all spheres of human activity. There is a commercial software offer to support most design activities. For example, there are many options for CAD-type packages, some of which offer specialized versions for different types of engineering applications, which give very important support in the area of detailed design, particularly regarding the drawing of parts, assembly of sets, dimensional verification, calculation of the volume of materials, etc. We can also mention the finite element analysis programs (FEA) that have streamlined the calculation process of the mechanical elements. This type of software is complemented by the concept generically known as "computer-aided manufacturing" (CAM), so that a chain has been integrated into the process of design and production of elements (Rinaldi *et al*., 2018).

This investigation arises due to the increase of the operational unavailability in the Goldwind S50/750 wind turbines models installed in the Wind Farm Gibara II. The faults that occur are closely related to the increase in temperatures in the components of the power train that the automatic system prioritizes. The power train is responsible for transmitting the power of the turbine to the electric generator, in one of two basic variants: power train with speed multiplier (Reder and Melero, 2018).

The studies of fluxes and heat transfer in equipment and machinery are usually addressed by computer-aided design and engineering software (CAD-CAE) tools that can simulate heat transfer. Dassault Systèmes with its SolidWorks program containing the Flow Simulation tool is very suitable for this type of study and greatly facilitates its evaluation (Rodríguez, 2017).

There are other companies that work in software programing, directly specialized in dynamic fluid simulation (CFD). An example of this is Ansys with its program Fluent, Flow Science with FLOW 3D, Siemens with FEMAP and Mentor Graphics with FLO-EFD. These programs, using a series of predefined mathematical models, are capable of

simulating experiments with fluid dynamics (Niu *et al*., 2018).

The Goldwind S50–750 wind turbines, installed in the Wind Farm Gibara II, are frequently disconnected when the wind speed increases above 11.5 m/s due to high temperatures in their components, mainly the winding of the generator and its front bearing. These automatic stops take approximately 30 minutes, until the wind turbine is restored. The technical unavailability time increases, now that the ideal conditions exist to produce high levels of energy.

Since the model of heat transfer inside the gondola is unknown, this makes it difficult to perform the causal analysis of the external manifestation of the problem: the automatic protection system disconnects the wind turbine due to high temperatures. Therefore, the model of the thermal behavior in the gondola of the Goldwind S50/750 wind turbine is studied using CAD-CAE tools, validating results using the equations and principles of heat transfer in the gondola of the Goldwind S50/750 wind turbines. It is possible to evaluate the thermal behavior in the gondola of the wind turbine if CAD-CAE tools and the fundamentals of thermodynamics are applied.

METHODOLOGY

The topics that were considered as the theoretical basis were the Goldwind S50/750 wind turbines models with its characterization and a systemic analysis of their operation. The fundamentals of heat transfer were necessary to know the mechanisms and laws by which each of these is governed. We used mechanics of fluids to have an overview about forced ventilation and computer-aided design (CAD) to show the tools that are used in technological processes and those that are associated with the evaluation of the behavior of fluids. In addition to this, catalogs, manuals, technical documentation and historical records of the functional states of the studied technology were consulted, out of which Table 1 was taken, where the characteristics of the wind turbine under study are represented.

Table 1: Technical Characteristics of the Goldwind S50/750 Wind Turbine
(Goldwind Science & Technology, 2008)

Manufacturer	Goldwind
Wind Turbine	
Type	Goldwind S50/750 (60 Hz)
	Fixed
Nominal Power (kW)	50
Rotor diameter (m)	50
Center height (m)	21,7
Rotor speed (min-1)	4
Connection speed (m/s)	14–15
Nominal speed (m/s)	25
Cut speed (m/s)	20
Lifetime (years)	59,5
Survival rate (3 seconds period) (m/s)	
Rotor	
Type	HT24
Blades Material	Fiber-reinforced glass resin
Blades quantity	3
Blades Length (m)	24
Direction	Horizontal Axis
Tilt angle (º)	5
Wind direction	Facing the wind (windward)
Rotational direction	Clockwise
Swept Area (m^2)	1963,5
Gearbox Type	FDG

The cooling system of the gondola is based on the intake from the outside air by the front of the gondola, where one part goes to the fan of the oil cooling system of the gearbox and the other part to cool the other components. The air entering from the rear is forced out of the environment by the fan of the cooling system IC411 of the generator (Goldwind Science & Technology, 2008). This hot air begins to come out from the top of the gondola, where the principle of heat transfer is used since the hot air rises and the cold air goes down as it is denser.

There is a relationship between the increase in wind speed and the temperatures recorded in the winding of the generator and the bearing that occupies position 1. Figure 1 displays the tendency to increase temperatures in relation to the increase in wind speed. When the wind speed exceeds 11 m/s, the temperature of these elements begins to transgress the working parameters established by the manufacturer. Therefore, the programmed automatic starts its protection functions before heating.

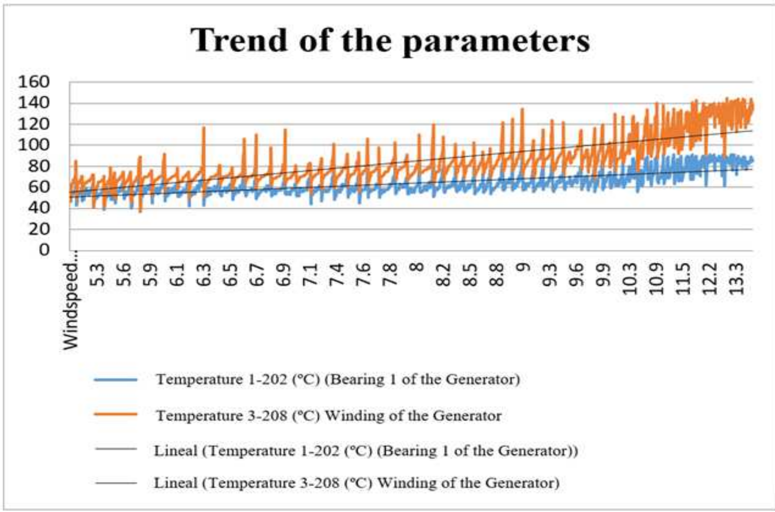


Figure 1: Trend of Temperature Parameters Recorded in the Generator.

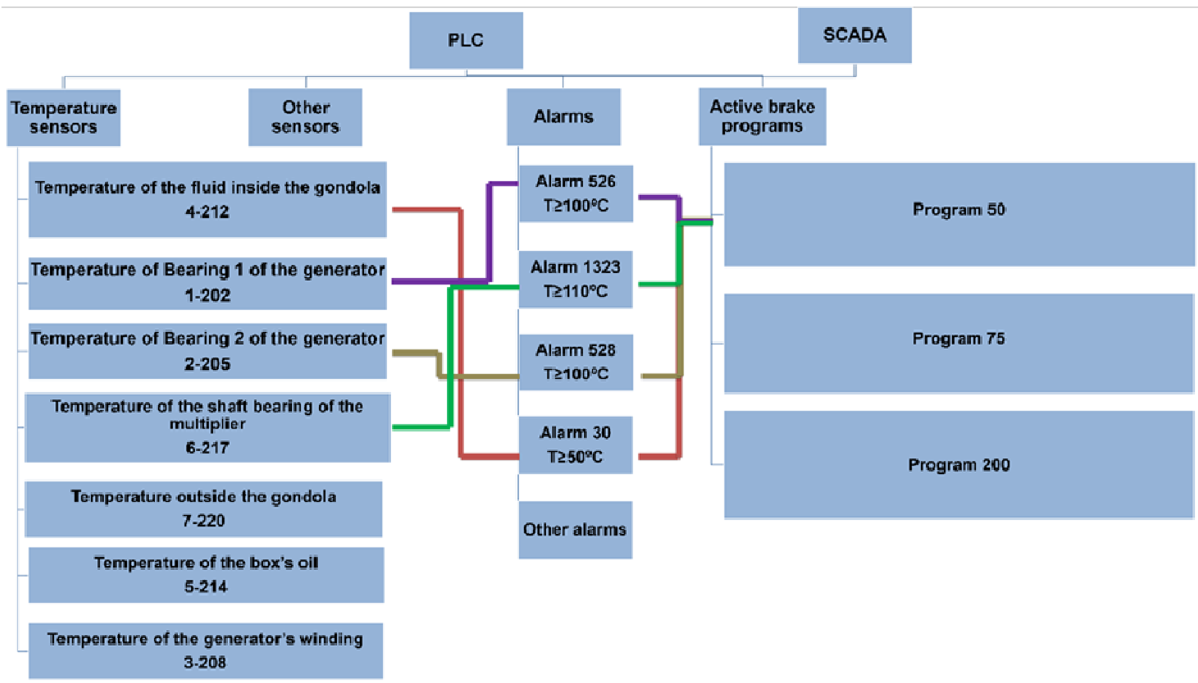


Figure 2: Flow Chart of the Automatic Control in the Wind Turbine.

Figure 2 displays how the relationship between the automatic and the brake systems work with regard to the temperature records inside the gondola. One can see how the PLC integrates sensors, alarms and brake programs. In this case, the increase in temperature causes the alarm to be triggered and the required brake program is activated immediately. During this process, it stops generating for 10 minutes, according to the manual of automatic (Goldwind Science & Technology, 2006), but in its actual application, from the moment it begins to lower the temperature until it turns on the systems, is calculated on an average time of 25 minutes according to the alarms recorded in 2014 – 2015, which motivates to look for a solution of the problem using CAD (computer-aided design), CAE (computer-aided engineering) technologies and software CAD-CAM-CAE that simulate thermal phenomena. "These technologies are being applied through the methods of concurrent engineering. The most developed technique in computer-aided engineering (CAE) is the application of finite element analysis (FEA), which with the improvement of computer devices has become an accessible technique for all users. These techniques are used industrially from design to manufacturing to optimize costs, quality, time, safety and others. Opening a space for Computational Fluid Dynamics (CFD), it is used to model the circulation and temperature air environment using the Navier-Stokes equations of Reynolds-Averaged (RANS) mechanical fluid equations. Large Eddy Simulation (LES) or Direct Numerical Simulation (DNS) of Navier–Stokes equations is computationally intensive and expensive for simulations of this class. Consequently, the vast majority of CFD simulations use the RANS equations along with a turbulence model (Valaer, 2011; Kayne and Agarwal, 2013). The analysis of the thermal behavior in the Goldwind S50/750 Wind Turbines installed in the Wind Farm Gibara II using CAD-CAE tools will be carried out using the following working algorithm displayed in Figure 3.

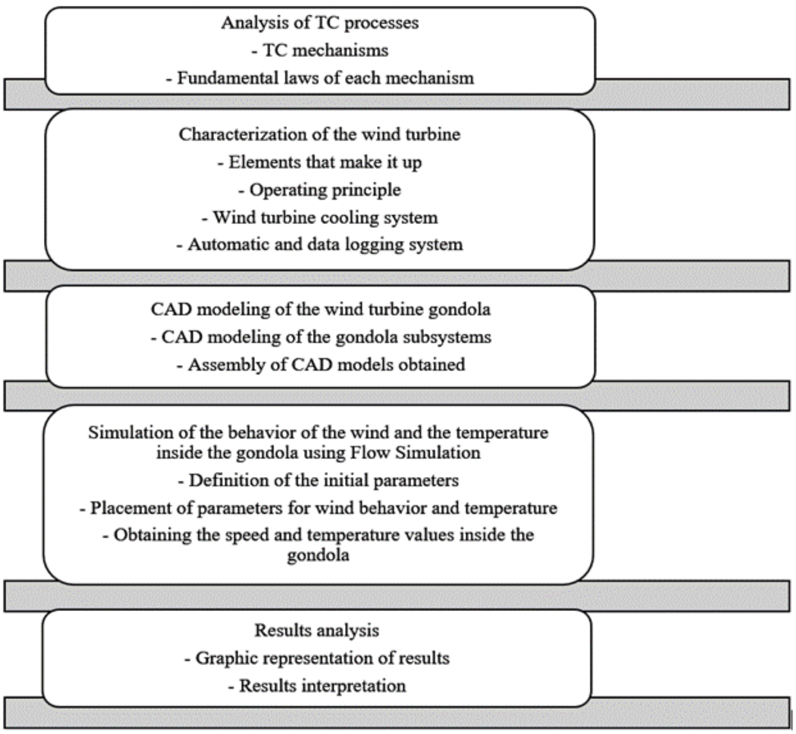


Figure 3: Procedure for the Evaluation of Thermal Behavior Inside the Gondola.

In order to study the behavior of the device, it was required to have a set of values that were provided by a database created in the wind farm. By doing so, it was possible to obtain Table 2, which displays generation of values, temperature of the measured elements, windspeed and direction, voltage and instant of time when the values were recorded.

Table 2: Ten-Minute Database of Temperatures in the Goldwind Wind Turbine Installed in Gibara, Cuba

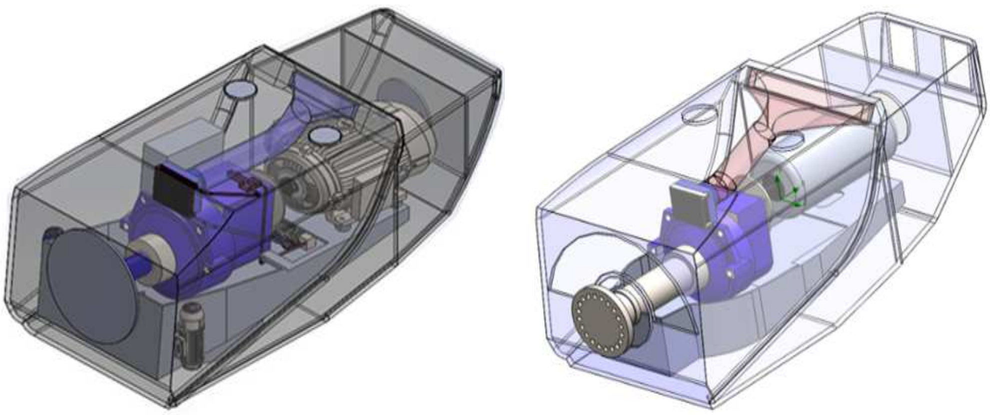
Time	Grid (kW)	Grid Voltage (V)	Temp. 1 202 (°C) GEN. Bearing	Temp. 2 205 (°C) GEN. Bearing	Temp. 3 208 (°C) GEN. Winding	Temp. 4 214 (°C) Gear oil	Temp. 5 217 (°C) Gear Bearing	Temp. 6 220 (°C) Outdoor	Wind Speed (m/s)
24/03/2017 21:40	707	397	94	73	139	68	74	27	137
24/03/2017 21:30	714	395	94	73	139	68	74	27	137
24/03/2017 21:20	728	396	94	73	138	68	73	26	146
24/03/2017 21:50	624	399	95	73	137	68	74	26	122
24/03/2017 21:10	721	400	93	72	137	68	73	27	143
24/03/2017 21:00	728	400	93	72	136	68	73	27	142
24/03/2017 20:50	704	399	93	72	135	68	73	27	135
24/03/2017 20:40	693	397	92	71	135	68	72	27	133
24/03/2017 20:30	718	395	91	71	135	68	71	27	139
24/03/2017 22:00	508	399	94	73	134	67	73	25	109
24/03/2017 20:20	727	393	90	70	133	67	70	27	142

After deep study of the working conditions, the bibliography and the information provided by the values of the sensors, we identified as dangerous combinations: the union of wind speed, the temperature of the winding of the generator, its bearing and the temperature of the oil with the activation of the braking systems, as established in the ranges established in the Programmed Logical Control (PLC).

The Goldwind S50/750 wind turbines installed in the Wind Farm Gibara II in 2011 under operating conditions of Cuba, for wind speeds exceeding 11.5 m/s, there are major aggregates, such as the gear box and the generator working subjected to temperatures that are not suitable for the functional state of the components that have revealed premature failures in the structure. For example, the cable of the tip-of-blade brake system. it was possible to appreciate that the element having the higher temperature is the winding of the generator and its front bearing as main heat sources. The heating of the wind turbine elements is causing stops that make the device unavailable for a while due to the activation of the alarms by the signal that some system is outside its working range.

RESULTS AND DISCUSSIONS

Figure 4 illustrates the developed CAD models for the gondola of the wind turbine under study.



(a) (b)

Figure 4: CAD Models for the Gondola of the Wind Turbine under Study, (a) General Assembly of the Gondola and the Subsystems and (b) Simplification of the Assembly.

Considering that all the walls of the control volume except the frontal to the gondola are at ambient temperature and pressure, all the parameters were applied as displayed in Figure 5.

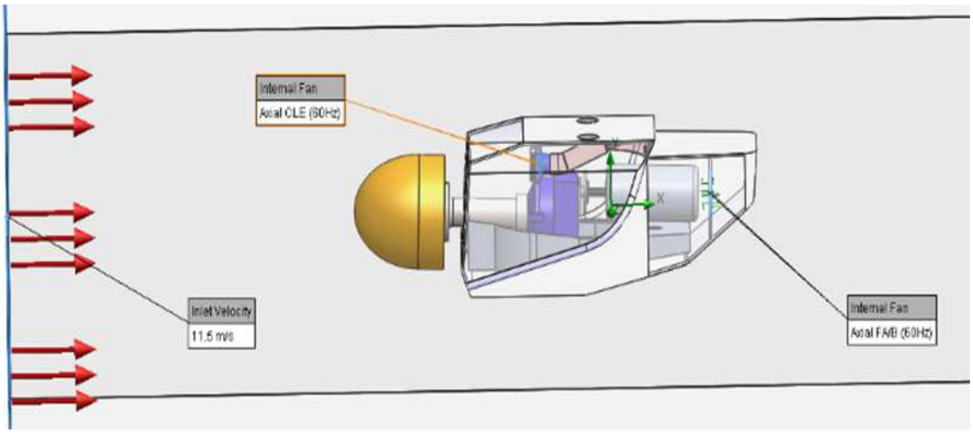


Figure 5: CAD Application of the Parameters.

Then the configuration of the mesh was made and the calculation of the fluid enclosed in the domain according to the inserted conditions. Making it possible to obtain Figure 6, where you can see the behavior of the wind inside and outside the gondola and the wind speed values. It was necessary to add the rotor to the assembly for this study because it is considered that its exclusion would influence the results.

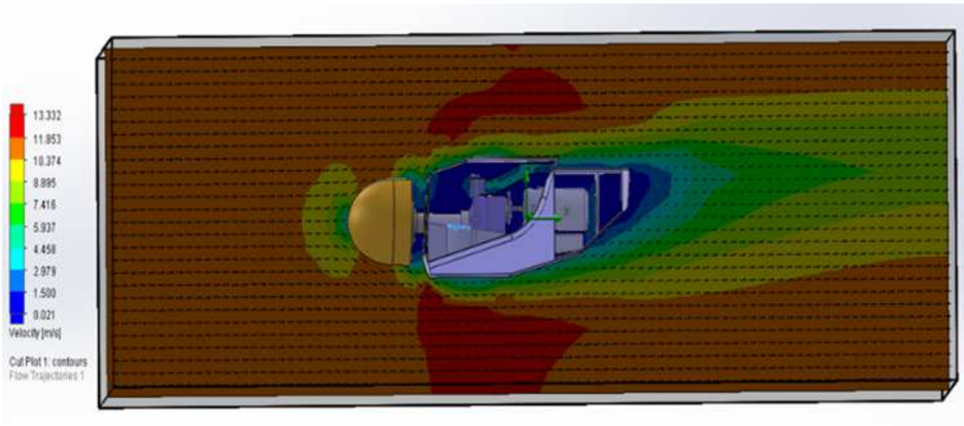


Figure 6: Simulation of the Behavior of the Wind Speed Inside and Outside the Nacelle.

To Know the Behavior of the Temperature inside the Gondola

For the study, it was necessary to place plugs to isolate the interior environment of the gondola from the outside. At this time, the simulation will only focus on the inside of the gondola. The speeds are already calculated above, and the temperature values obtained in the measurements of the devices will serve as the parameters to be defined as boundary conditions. The type of material of the elements in which heat transfer intervenes must also be defined.

These would be the data:

Front input speed: 1.5 m/s.

Rear entry speed: 1.2 m/s.

Output air speed of the oil ventilation duct: 1.7 m/s.

Temperature of the generator winding: 403 K

Oil temperature of gearbox crankcase: 333 K

Oil temperature in the radiator: 333 K

Temperature of the bearing that supports the gearbox shaft: 347 K

Temperature of bearing 1 of the generators: 368 K

Temperature of bearing 2 of the generators: 345 K

Type of material:

Gondola: Fiberglass.

Radiator: Copper.

Conduit of the oil cooling system: Fiberglass.

Considering that the gondola is isolated from external factors, all the parameters were applied as revealed in Figure 7.

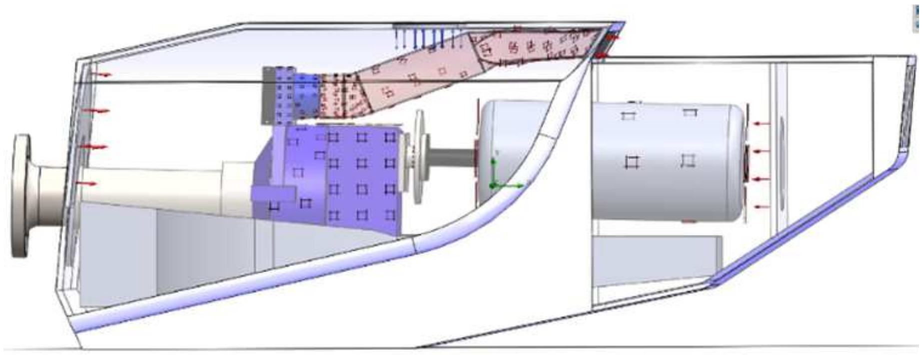


Figure 7: Definition of Parameters for Thermal Simulation.

Then the mesh is verified according to the conditions of the computer and the study is executed by continuing the previous calculation. After the study is executed, the cuts of the planes began to be inserted to obtain the information of the results and how the fluid behaves thermally inside the gondola. Figure 8 provides a graphical representation for a study of stationary points of the behavior of temperatures in full correspondence with the recorded measurements.

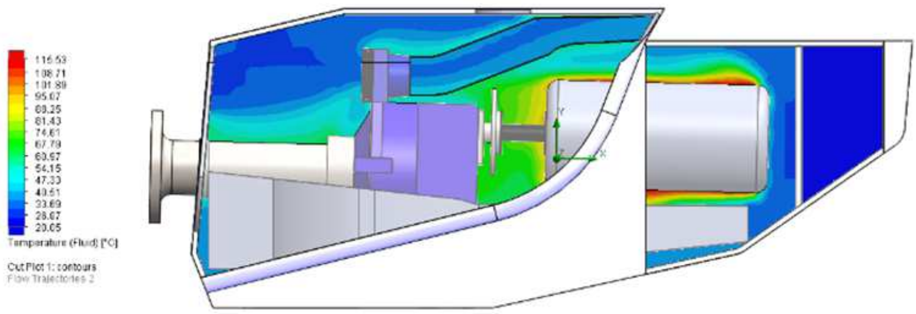


Figure 8: Graphic Representation of Temperature Behavior.

As can be seen in the previous figure, the temperature values average between 323 K (50° C) and 353 K (80° C). The environment inside the gondola should be around 308 K (35° C) since the oil cooling system fan turns on at this temperature and does not shut off until it reaches 303 K (30°C), an event that never happens. That is to say, the fan is in operation practically during the whole generation process. Since the average thermal state of the gondola is higher than 323 K (50°C), it can be said that the blade brake is used with a fairly high frequency, which can affect the mechanical operation

of the brake, since it was not designed for those conditions. In figure 9, you can see how the heat flow behaves. In this part, it would be revealing the union of studies 1 and 2, how air and temperature behave inside the gondola. There is a total pertinence between the simulated results and those measured during the studies carried out.

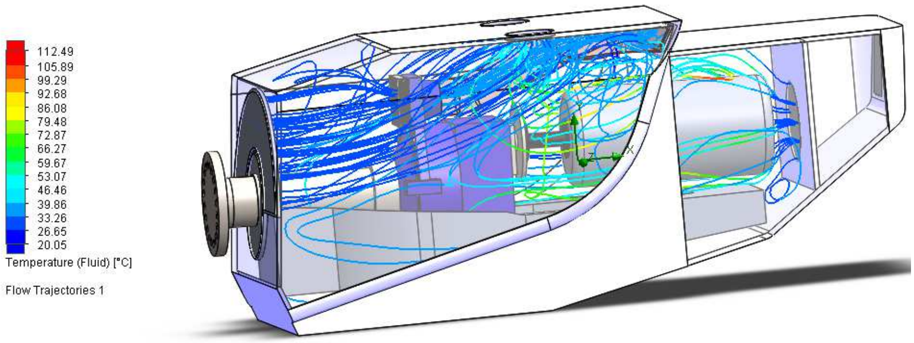


Figure 9: Heat Flow behavior.

Here, we can see the flow lines with the temperature value, where the air outlet is at the top of the gondola, taking into account that the hot air rises and the cold one descends, to take advantage of this condition in the air-conditioning of the wind turbine.

CONCLUSIONS

With CAD-CAE tools, models and studies of thermal behavior were obtained in the Goldwind S50/750 Wind Turbines installed in the Wind Farm Gibara II. It is validated that the systemic analysis of the working conditions in the gondola, with the CAD/CAE tools allow to optimize time, resources and actions in a predictive way to guarantee the desired operational reliability in the studied devices.

It was defined that the temperatures inside the gondola range between 20.05ºC and 115.53ºC with an average value of 67.79ºC, a value that is higher than that established by the manufacturer.

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